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Continuous Development of the 3D Hybrid Metal Printer & Printing Process

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ABSTRACT

This research article presents the ongoing continuous improvements that are currently being applied and implemented with the 3-D Hybrid Metal Printer located on Western Michigan University's engineering campus. The 3-D Hybrid Metal Printer uniquely manufactures metal components with the use of a patented process that integrates an additive and subtractive manufacturing method. This additive manufacturing method uses a form of bonding called gas metal arc welding (GMAW). This deposits material along a predetermined and calculated path that matches the geometrical shape of the component being manufactured. Once the first layer of material is deposited, the subtractive manufacturing method implements the use of a computer numerical controlled machine (CNC) to machine the component. This process is repeated until the component has meet the required geometrical specifications. Improvements that have recently been applied and are currently being used include an upgraded mounting configuration for the GMAW arm, a custom coolant reservoir with drip tray, a 3-D scanning system, safety equipment with elevated safety procedures, and weld pattern configuration optimization. These improvements not only decrease the time required to manufacture components, but also increases the sustainability of this patented technology.

KEYWORDS: *3-D Hybrid Metal Printer, additive manufacturing, subtractive manufacturing, computer numerical controlled machine (CNC), gas metal arc welding (GMAW), Forest River Inc., 304 stainless steel, stepper motor, 3-D scanning system, weld pattern optimization, machine feedrate, G & M codes.*

Continuous Development of the 3D Hybrid Metal Printer & Printing Process

INTRODUCTION:

The 3-D Hybrid Metal Printer is capable of manufacturing metal printed components without the use of standard manufacturing practices or the more commonly available plastic 3-D printers. Even though plastic 3-D printers are easily available and have their advantages, they lack the more advanced advantages metal printing printers retain.These advantages of the 3-D Hybrid Metal Printer, located in Western Michigan University's manufacturing laboratory, include the integration between the additive and subtractive manufacturing method, the removal of the need for support material or sub-structure, and the ability to manufacture complex geometrical components.

For these reasons, prototype orders from companies, such as Forest River Inc.; A Berkshire Hathaway Company, require critical tolerances to be met to ensure proper function when the components move to a large mass production scale. Figure 1 shows in-process printing of a cam bar lock, supplied by Forest River Inc., which is used in their numerous recreational vehicle manufacturing facilities.

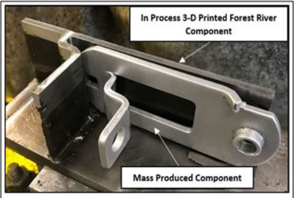


Fig. 1
3-D Metal Printed Part In-Process

The manufacturing of this 3-D metal printed component was carried out due to Forest River's incoming purchase order for one metal printed component. This component will be tested at Forest River's engineering test facility to check the performance and strength and to determine if results fall short, match, or exceed the mass produced component. These continuously printed components allow for future companies to purchase and invest in this patented 3-D Hybrid Metal Printer technology.

Once all additive layers were printed, and the total height of the printed component exceeded the actual required height, it was removed from the base plate so the final subtractive manufacturing process could be completed. G & M programming language codes were used in tandem with the CNC machine for the corner radiuses, large orifice opening, and the three required mounting hole locations. The component was then coated with a painting primer to allow protection for the mild steel material from corrosion. This

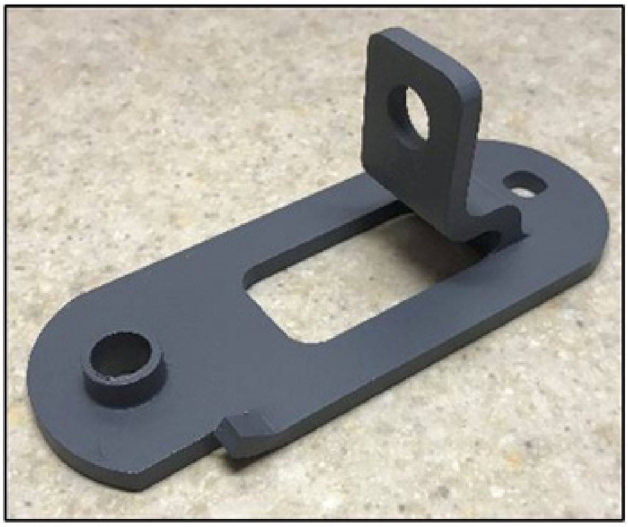


Fig. 2
Completed Forest River Inc. Printed Cam Bar Lock

primer also protects the machined surface finish integrity.

This printed component was a large printing process discovery in which numerous future implemented tests originated from for optimization. These tests and experiments will be discussed further within this research article.

To confirm that no surface defects were present on the printed component, x-rays were taken with a top and side profile view showing of their absence.

Fig.3
X-Rays of 3-D Printed Component

Upcoming testings of 3-D printed components will include industrial CT scanning to ensure internal porosity is at a minimum. Internal porosity is an important aspect to study since it can have a direct effect on mechanical properties of a printed component [1]. A high level of porosity concentration in one area could lead to a catastrophic failure resulting in possible injury or death depending on how the component is utilized and in what setting. When this impending industrial CT scanning has been finalized, concerns about porosity within the printed metal with the 3-D Hybrid Metal Printer will be dissolved.

A live functioning display was created to test the average person's, or someone with no metal printing experience, ability to identify a 3-D printed component versus a standard mass produced component. The display offers the selection to choose between either A or B. Orange paint was used to identify the component that is in question of being 3-D metal printed. Undergraduate students from Western Michigan University were used to conduct the survey. Majority of the students took an educated presumption on which one they concluded was 3-D metal printed. This result was actually wanted since one of the goals of using the 3-D Hybrid Metal Printer is to be able to identically recreate components with no form of identifying the difference. For personal curiosity and inspection, this display is located in the metrology lab on Western Michigan University's engineering campus.

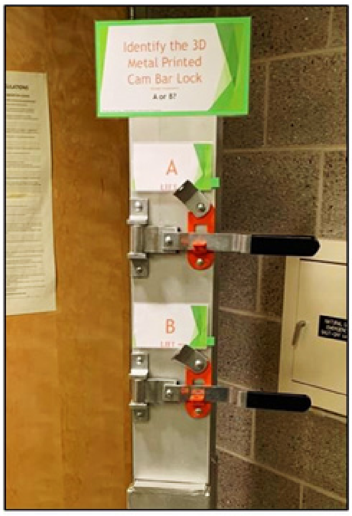


Fig. 4
Cam Bar Lock Display

Overall, the 3-D metal printing of this component was successful with regards to fit, function, and usability. Numerous progressive 3-D metal printing techniques were observed while operating the 3-D Hybrid Metal Printer and modified to allow future metal printed components to have a successful end result. With the high approval and continuing support from Forest River Inc., along with other interested companies, purchase orders have been placed and will continue to be placed to further advance optimization of the metal printing process.

II. GAS METAL ARC WELDING MOUNTING CONFIGURATION

The GMAW arm mount was original attached to the CNC machineby means of an electronic actuator which was controlled by a three-way toggle switch. This electronic actuator was then mounted using steel plates and brackets.

Fig. 5
Original GMAW Arm Mount Configuration

This GMAW arm mount configuration functioned and components were able to be printed but contained many flaws, deficiencies, and limitations.

These weaknesses and deficiencies included:

1. The inability to accurately measure the Z-axis position when the actuator was activated to raise and lower the arm causing positioning errors.
2. Due to the instability of the mounting configuration, repeatability of obtaining the negative Z-axis position was challenging.
3. There was no feed wire cable support which would cause wire binding and failure.
4. The configuration was constructed of steel which caused unnecessary excess weight to be added.
5. Location of the GMAW arm mount restricted possible additional equipment to be adhered to the CNC machine.
6. The switch was located in an inconvenient position which also had exposed wiring present which could cause electrical shock to the operator.
7. The overall design and layout had a disorganized appeal which could impact possible upcoming company demonstrations and presentations.

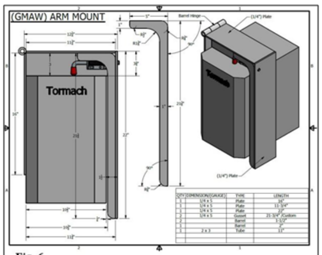


Fig. 6
New Aluminum GMAW Arm Mount Configuration

With these deficiencies in mind, a new GMAW arm mount was designed, engineered, and manufactured with the help of CAD modelling software.This new GMAW arm mount was designed to be constructed entirely out of 6061 aluminium with the exception of the mounting bolts and hinge pins, which were comprised of steel. This newly designed GMAW arm mount was installed in the opposite location that the previous GMAW arm mount was located. This decision was made to allow additional equipment, such as multi-tool changers and scanner mounts to be adhered to the CNC machine. Once the CAD model was complete and finalized the manufacturing stage took place which followed the specifications as noted in Figure 6. Attachment to the CNC machine consisted of four mounting locations on the spindle housing unit.

The hinge system on the GMAW arm mount is implemented when a tool change is required while the subtractive manufacturing process is being conducted. This system is only temporary as the hinge system will only be required for CNC machine maintenance once the multi-tool changer system has been installed which can now be mounted properly due to the design and manufacturing of this new GMAW arm mount. When the GMAW arm mount is securely fastened, the GMAW arm itself has to be physically attached so the additive manufacturing process can be implemented. To accomplish this, a stepper motor was secured and mounted so that the vertical position of the GMAW arm itself could be raised and lowered. Two mounting locations, as seen in Figure 8, strengthens the rigidity of the GMAW arm to allow minimal movement during the additive operation.

Fig. 7
New Mounted Aluminum GMAW Arm Mount

The stepper motor is connected to a speed regulator that controls the positive and negative Z-axis travel. When the stepper motor reaches the maximum negative Z-axis value, the limit switch engages resulting in the stepper motor disengaging. This is the same for the positive Z-axis value direction as well.

Fig. 8
Mounted Stepper Motor

Once the limit switch is activated in the maximum positive Z-axis direction, the stepper motor will disengage. This allows consistent repeatability with the location of the GMAW arm which increases efficiency for the additive manufacturing process.

This newly designed GMAW arm mount adds overall significant improvement in both reliability and efficiency when it comes to operating the 3-D Hybrid Metal Printer. Due to the one-hundred-eighty degree GMAW arm that is currently attached, the additive and subtractive manufacturing process is limited to a restricted printing area. Research, design, and prototyping will be implemented to further improve the GMAW arm mount by relocating the additive process closer to the subtractive process. The one-hundred-eighty degree GMAW arm will be replaced with a reduced degree of angle with possibilities ranging from thirty to sixty degrees. This will allow the 3-D Hybrid Metal Printer to manufacture larger prints and utilize valuable printing workspace.

III. COOLANT RESIVOR & DRIP TRAY

During the subtractive manufacturing process on the 3-D Hybrid Metal Printer, a large amount of heat is generated causing premature tool wear which could result in tool and component additive layer damage. The use and implementation of cutting and grinding fluid was considered necessary for the subtractive manufacturing process moving forward to ensure components being printed in the subtractive process did not cause unnecessary tool wear. Trim MicroSol 585XT Cutting and Grinding Fluid was used to reduce the opportunity of likely occurrences. This lubricant was chosen due to the wide range of material applications which could match the 3-D Hybrid Metal Printers current metal material printing list. In order to reuse this cutting and grinding fluid, a coolant reservoir and drip tray were designed using 6061 aluminium to fit below the designated storage area of the CNC machine. The pump that is used for the transfer of lubricating cutting fluid from the coolant reservoir to the spray nozzle is

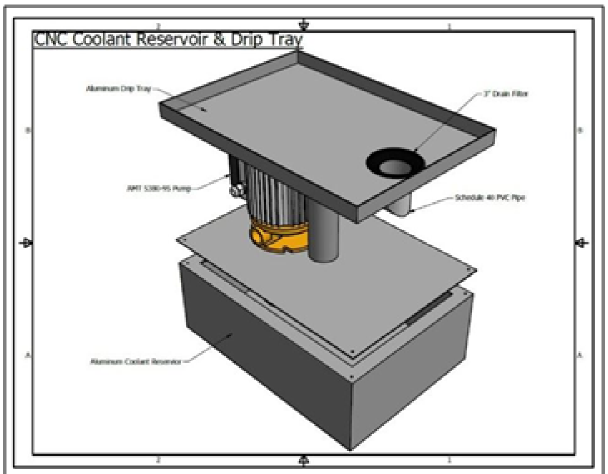


Fig. 9
CNC Coolant Reservoir & Drip Tray

Fig. 10
Installed CNC Coolant Reservoir & Drip Tray

Fig. 11
Spray Nozzle

an AMT one-eight horsepower immersion pump. This pump is capable of pumping fifty-six gallons per minute which is more than sufficient to ensure proper flooding of the work area [3]. When the subtractive manufacturing process is executed, a switch is activated causing the lubricating cutting fluid to flood the machining area by means of a spray nozzle. Stainless steel braided hose lines were used so interaction with the additive manufacturing process would be minimal.

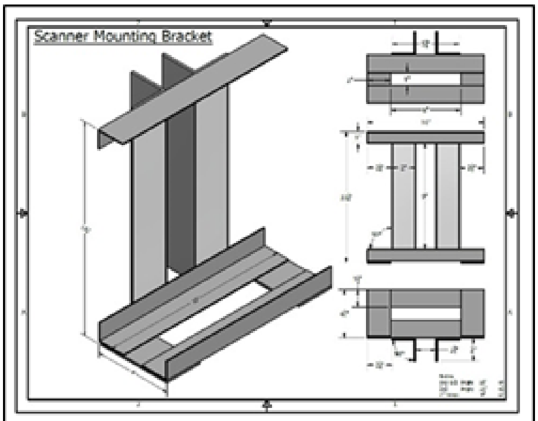


Fig. 12
Scanner Mounting Bracket

Fig. 13
Installed Swing Arm & Scanner

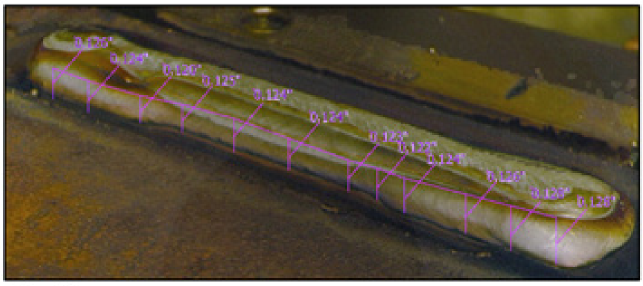


Fig. 14
First Additive Manufacturing Layer

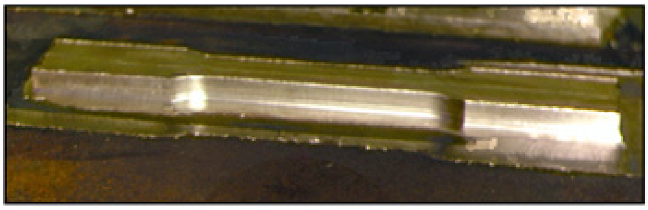


Fig. 15
First Subtractive Manufacturing Layer

After the lubricating cutting fluid is used and exits the spray nozzle, it drips down into the drip tray. The machined chips are separated from the lubricating cutting fluid in the drip tray and the lubricating cutting fluid flows back into the coolant reservoir to be again pumped back to the spray nozzle. This cycle is repeated until the subtractive manufacturing process has been completed.

IV. SCANNING SYSTEM

In order to properly document the 3-D metal printed component as printing is implemented, a laser scanner was deployed to document each additive layer before and after the additive and subtractive manufacturing process was completed. Before the laser scanner could be implemented, mounting configurations had to be designed and engineered in order to mount the laser scanner securely to the 3-D Hybrid Metal Printer. A steel swing arm was installed to allow pivoting and a high range of mobility to the laser scanner mounting bracket in multiple axial directions. This allowed multiple angles of the component to be scanned.

When scanning is ready to commence, the swing arm is manually positioned to the desired location. The laser scanner currently being used on the 3-D Hybrid Metal Printer is a NEXTENGINE laser scanner. This laser scanner has a detailed accuracy of five-thousandths of an inch with the capability of producing mesh files that can be exported into CAD software for further documentation and manipulation [5]. The component that was scanned for the extraction of experimental measurement data was a 304 stainless steel tensile test specimen which was manufactured to test the strength of the material. When the additive process is adding the material, uniformity of the layer height possesses a challenge for consistency. This problem was overcome through pattern configuration optimization and will be discussed in further detail later in this research article. The data measurements obtained from this NEXTENGINE laser scanner will be used for further implementations of machine learning to allow auto-corrections to be made with the additive process while continuously printing.

V. SAFTEY PROCEDURES & PROTOCOLS

While working with many potentially dangerous machines in machining laboratories, safety should be, and remain, the top priority while conducting any experimental testing. This was never overlooked while operating the 3-D Hybrid Metal Printer at Western Michigan University. Additional steps and improvements were taken and created to ensure that safety remained the highest priority.

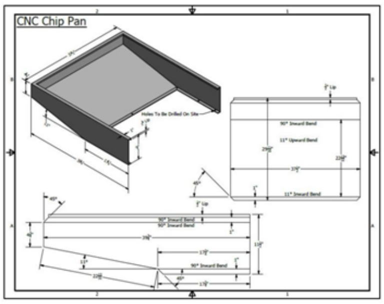


Fig. 16
Safety Chip Pan

In order to create a safe work environment, a chip pan and back guard were designed and manufactured to allow a semi-enclosed surrounding. These are useful for both the additive and subtractive manufacturing process. For additive, these barriers create a protective stop to ensure that sparks and molten material do not escape the designated printing area. This applies for the subtractive manufacturing process as well, but instead of sparks, hot chips are produced. In either manufacturing process scenario, injury to the operator could result. The use of the chip pan and back guard reduce this outcome significantly.

The GMAW additive manufacturing process emits a light that can be damaging to the human eye if looked directly on. This light can cause temporary or permanent blindness. Since multiple layers are needed to print a complete component, increasing the number of times an innocent bystander could be harmed, a warning system was installed to ensure that bystanders in the vicinity are aware to take precautionary measures. This safety system is in form of an amber strobe light. Before the additive process commences, a switch is activated to the on position. When the additive process concludes, the switch is deactivated to the off position. This simple and easy to use system can save numerous accidents before they can occur.

As these abundant safety features were being adhered to the 3-D Hybrid Metal Printer, significant rewiring was done to allow switches to be relocated in one centralized location. When wires were ran, they were all covered with corrugated loom tubing to ensure no accidently splicing or loss of connection occurred. This relocation allows for a quick response in case certain operations have to be immediately terminated.

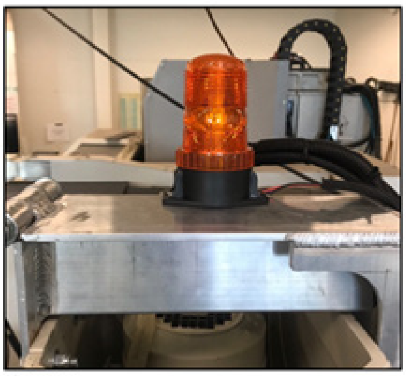


Fig. 17
Warning Light System

With these added safety features and procedures, current and future operators of the 3-D Hybrid Metal Printer can rest assured that a safe working environment remains an important task for all current and future printing.

VI. WELD PATTERN OPTIMIZATION

Metal additive manufacturing, as with any metal printing process, produces challenges for successful prints. One challenge that hounded the 3-D Hybrid Metal Printer is inconstant uniformity in the additive layer height and width. Up until this point, the 3-D Hybrid Metal Printer printed additive layers with straight line internal and perimeter formations. This formation can be noted in Figure 18 with the distinct sketch lines in the tensile test specimen CAD file.

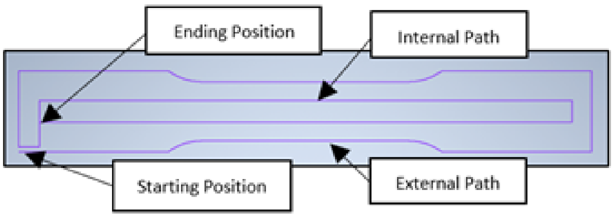


Fig. 18
Straight Line Additive Manufacturing

Disadvantages witnessed with this practice included material plunge when reversing directions during printing as well as inconsistent height and width uniformity throughout the print. When printing components, controllable variables on both the GMAW welder and the CNC machine were taken into account. Controllable variables on the GMAW welder include wire feed speed and trim while on the CNC, machine feedrate controls the speed in which the GMAW arm moves around the CNC worktable [6]. Both machine feed rate and wire feed speed are measured in inches per minute. To combat inconsistent additive uniformity, pattern formations were created to attempt to reduce and possibly eliminate these issues. The controllable variables that were altered in these experiments were CNC machine feed rate, pattern configuration width, and the degree in which the GMAW arm travelled in the pattern. The wire feed speed and trim on the GMAW welder remained constant during these experiments. These controllable variables on the GMAW welder will be tested on during future experiments to witness if improved optimization can be achieved with altered parameter settings.

To start, a control plate sample, Figure 19, was created to show multiple two-and-a-half-inch straight line additive passes with machine feedrates that ranged from six to twenty. Early testing showed a machine feedrate greater than twenty resulted in additive layers that were unable to be measured due to the increased speed. This test showed that width and height consistency was difficult to maintain between all the machine feedrates tested.These additive layers were coated with painting primer for an enhanced visual appearance and to ensure corrosion did not occur.

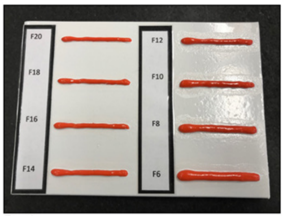


Fig. 19
Experimental Straight Line Additive Manufacturing

Since components being printed can vary in thickness, the "Z" pattern configuration was tested with three different widths along with multiple angle parameters. These widths included one-eighth of an inch, one-quarter of an inch, and three-eighths of an inch. The one-eighth of an inch test was conducted with angle parameters of forty-five degrees, sixty degrees, and seventy-five degrees. The one-quarter of an inch test was conducted with angle parameters of forty-five degrees, sixty degrees, and seventy-five degrees. And finally, the three-eighths of an inch test was conducted with angle parameters of fifteen degrees, thirty degrees, and forty-five degrees. Pre-initial testing showed that the three-eighths of an inch test with angles greater than forty-five degrees would result in "Z" pattern configurations that would not pertain to conductive additive manufacturing layers. This is why the angle of approach was reduced for this test to fifteen, thirty, and forty-five degrees.

The results of the one-eighth of an inch "Z" pattern configuration were as follows. Constant uniformity in height and width could be witnessed on the one-eighth of an inch experiment in all the three degree parameters.The one-eighth of an inch "Z" pattern configuration with a forty-five degree path showed that a component can be printed with a width range between one-quarter and seven-sixteenths of an inch. The one-eighth of an inch "Z" pattern configuration with a sixty-degree path showed that a component can be printed with a width range between two-tenths and three-eighths of an inch. The one-eighth of an inch "Z" pattern configuration with a seventy-five-degree path showed that a component can be printed with a width range between one-tenth and three-tenths of an inch. The conclusion to this experimental test showed that if a desired component width between two-tenths and seven-sixteenths of an inch is desired any of the three angle pattern configurations can be used to achieve this as long as the corresponding machine feedrate is selected. These additive layer results are shown in Figure 20.

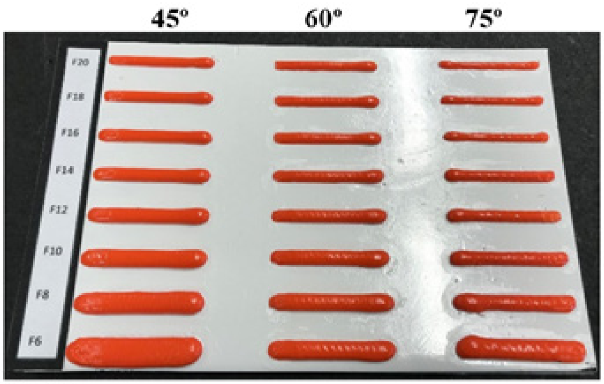


Fig. 20
Experimental "Z" Configuration: 0.125", 45º, 60º, 75º

The results of the one-quarter of an inch "Z" pattern configuration were as follows. Constant uniformity in height and width could be witnessed in only a single degree parameter which was forty-five degrees. The sixty and seventy-five degree parameters slowly started becoming uniform in width but did not completely succeed. A visible outline of the "Z" pattern configuration was present, even with the slowest machine feedrate attempted of eight. The one-quarter of an inch "Z" pattern configuration with a forty-five degree path showed that a component can be printed with a width range between one-eighth and four-tenths of an inch. The labels N/A signify that the additive

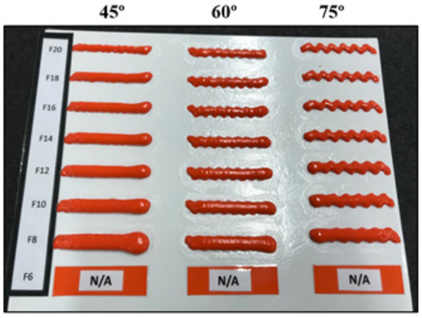


Fig. 21
Experimental "Z" Configuration: 0.250", 45º, 60º, 75º

manufacturing process could not take place due to excessive heat produced on the test plate. This excess heat produces warpage in the plate due to the extended time of concentration in a small area. The conclusion to this experimental test shows that if a component is to be printed to have a desired width between one-eighth and four-tenths of an inch, the one-quarter of an inch forty-five degree "Z" pattern configuration with the corresponding machine feedrate should be implemented. These additive layer results are shown in Figure 21.

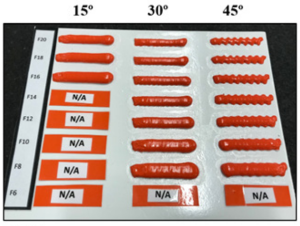


Fig. 22
Experimental "Z" Configuration: 0.375", 15º, 30º, 45º

The results of the three-eighths of an inch "Z" pattern configuration were as follows. Constant uniformity in height and width could be witnessed on the three-eighths of an inch experiment in two degree parameters, fifteen and thirty degrees. The three-eighths of an inch "Z" pattern configuration with a fifteen-degree path showed that a component can be printed with a width range between four-tenths and seven-sixteenths of an inch. The three-eighths of an inch "Z" pattern configuration with a thirty-degree path showed that a component can be printed with a width range between one-quarter and one-half of an inch. Another visible outline of the "Z" pattern configuration was present on the forty-five degree path, even with the slowest attempted machine feedrate of eight. The labels N/A again signify that the additive manufacturing process could not take place due to excessive heat produced on the test plate. The conclusion to this experimental test shows that if a component is to be printed to have a desired width between four-tenths and one-half of an inch, the three-eighths of an inch fifteen or thirty degree "Z" pattern configuration with the corresponding machine feedrate should be implemented. These additive layer results are shown in Figure 22.

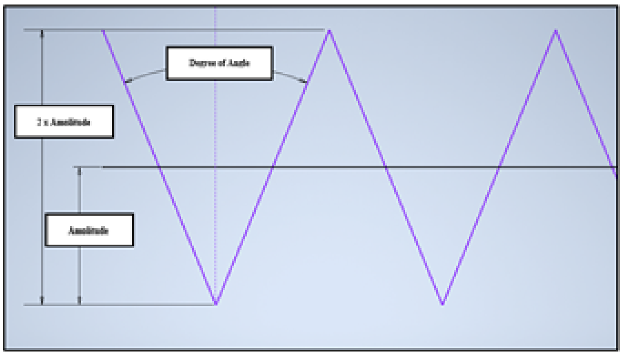


Fig. 23
"Z" Configuration Path

In conclusion to these experimental tests, three factors control the constant uniformity for the overall width of the additive layer: "Z" pattern configuration width, degree of angle, and machine feedrate. Since each component printed is unique in geometrical shape, each need to be considered when starting a new component on the 3-D Hybrid Metal Printer. Consult the graph in Figure 24 when determining "Z" pattern configuration width, degree of angle, and machine feedrate to implement. When selecting the additive layer, ensure that the overall width will be wider than the actual printed component. This will ensure that there will be enough material to be machined in the subtractive manufacturing process.These experimental additive layer tests can be observed in the metrology lab on Western Michigan University's engineering campus.

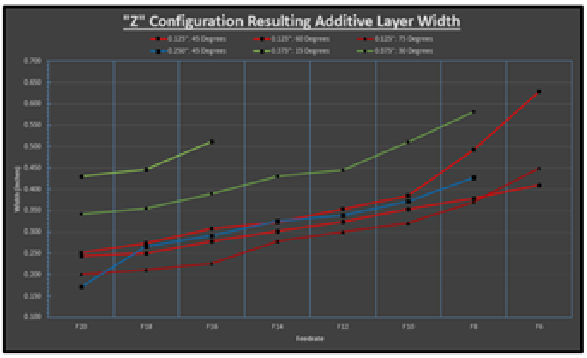


Fig. 24
"Z" Configuration Path Resulting Widths

VII. 304 STAINLESS STEEL TENSILE TESTS

In order to ensure that 304 stainless steel is a viable material to use with the 3-D Hybrid Metal Printer, tensile test specimens were printed to be tested. These test specimens were printed using the International Organization for Standardization specifications using DIN EN ISO 6892-1. This testing standard reduces the fluctuation in test accelerations when testing an array of multiple

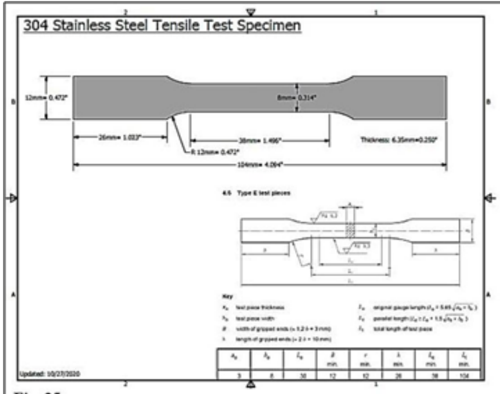


Fig. 25
DIN EN ISO 6892-1 Test Specifications

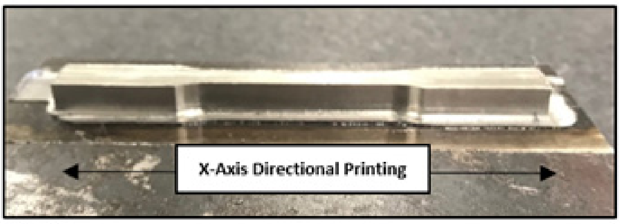


Fig. 26
Stainless Steel X-Axis Directional Print

specimens which results in the reduction of measurement variability [7].

A total of five tensile test specimens were sent to Element, a tensile testing facility located in Wixom, Michigan. The first three test specimens printed were using a layer formation in the X-axis direction. Two of these printed had a thickness of one-quarter of an inch while the other had a thickness of five-sixty-fourths of an inch.

The next two specimens printed were printed in the Z-axis direction. Both were printed with a thickness of one-quarter of an inch. Specimens were printed in both the X and Z-axis directions is to ensure proper adhesion of each layer is achieved with each additive layer. Components that are printed for real world applications may endure both X and Z-axial stress and strains. Once the required height of the Z-axis additive layer was obtained, the print was rotated to be machined into the standard specified tensile test specimens.

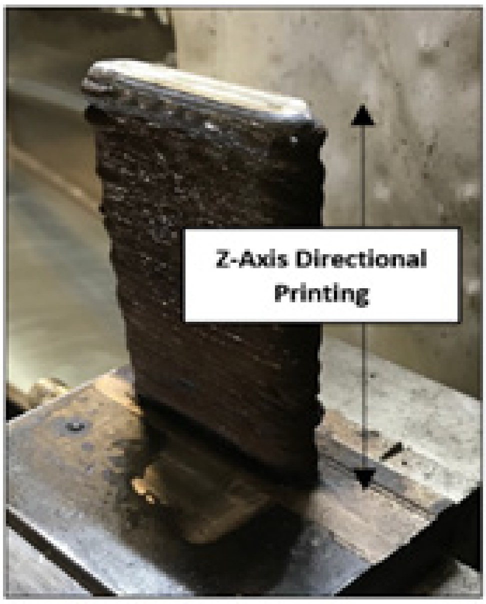


Fig. 27
Stainless Steel Z-Axis Directional Print

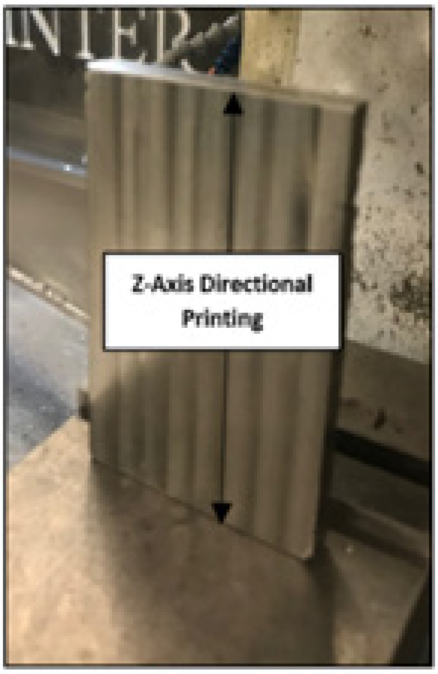
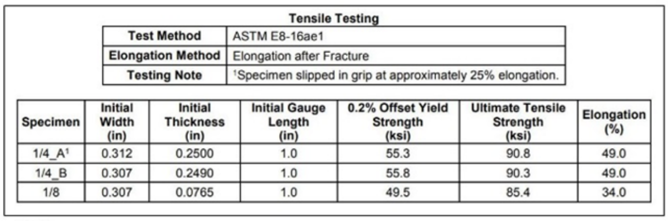


Fig. 28
Stainless Steel Z-Axis Directional Print Machined

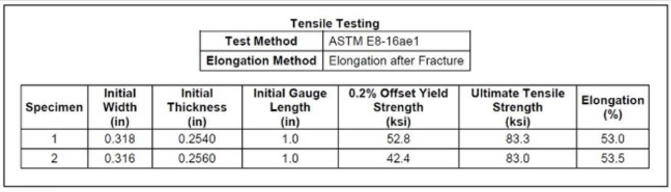


Tensile Testing

Test Method	ASTM E8-16ae1
Elongation Method	Elongation after Fracture
Testing Note	[1]Specimen slipped in grip at approximately 25% elongation.

Specimen	Initial Width (in)	Initial Thickness (in)	Initial Gauge Length (in)	0.2% Offset Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
1/4_A[1]	0.312	0.2500	1.0	55.3	90.8	49.0
1/4_B	0.307	0.2490	1.0	55.8	90.3	49.0
1/8	0.307	0.0765	1.0	49.5	85.4	34.0

Fig. 29
304 Stainless Steel Tensile Test Results X-Axis Directional



Tensile Testing

Test Method	ASTM E8-16ae1
Elongation Method	Elongation after Fracture

Specimen	Initial Width (in)	Initial Thickness (in)	Initial Gauge Length (in)	0.2% Offset Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
1	0.318	0.2540	1.0	52.8	83.3	53.0
2	0.316	0.2560	1.0	42.4	83.0	53.5

Fig. 30
304 Stainless Steel Tensile Test Results Z- Axis Directional

The tensile test results from Element showed that the ultimate tensile strength from both X-axis and the Z-axis directional printing exceeded the standard ultimate tensile strength at room

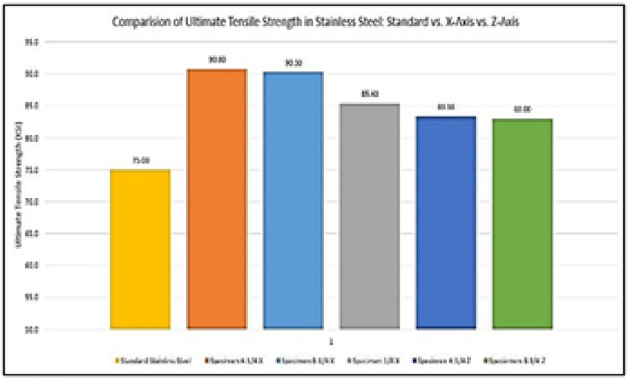


Fig. 31
304 Stainless Steel Tensile Ultimate Strength Comparison

temperature for 304 stainless steel of seventy-five kilopound per square inch [8]. The X and Z-axis printed test specimens exceeded the standard ultimate tensile strength of 304 stainless steel by over twenty percent and ten percent respectfully. X-axis directional printing specimen A and B, one-quarter of inch in thickness, reached over ninety kilopounds per square inch. The five-sixty-fourths specimen reached eight-five kilopounds per square inch. With the third X-axis specimen being under one-half the thickness of the first two X-axis specimens, results showed that the ultimate tensile strength only diminished by less than six percent.

The Z-axis directional printing specimens one and two, one-quarter of inch in thickness, reached over eighty-three kilopounds per square inch. More tensile test specimens will be manufactured to create a concrete average of both X and Z-axis directional printing. These current X and Z-axis directional tensile printing tests proves that this patented hybrid metal printing process can create components that comply with standard material properties in this unique form of manufacturing.

In conclusion, the additive manufacturing process using 304 stainless steel on the 3-D Hybrid Metal Printer had exceptional successful results with X and Z-axis directional printing. These results can be used as foundational support for complex geometrical shaped components when X and Z-axis directional printing is required.

VIII. UPCOMING EXPERIMENTS & TESTING

As continuous experimental tests are implemented and carried out, new questions and ideas are formed on what the limits and possibilities are with the 3-D Hybrid Metal Printer. In the coming months, new materials will be selected to hopefully add to the continual successful printed list of materials. The materials being considered include titanium, nickel, bronze, and copper. Components that will be printed with this new material, titanium in particular, will be an internal hip replacement component regularly used in the medical field for hip replacements. Manufacturing this component will not only further advance the 3-D Hybrid Metal Printer printing capabilities but can open the door to more advance medical device implant manufacturing. Pattern optimization will also continue to determine if a path out preforms the current "Z" pattern configuration.

New printing techniques will also be examined. One in particular is the non-machining of each additive layer after the additive process has completed. Currently, after each additive layer is deposited, each additive layer is surfaced in the subtractive manufacturing process. If this process can be semi-eliminated or completely avoided entirely, this would save valuable time and material. Tensile tests will again need to be manufactured to ensure there is no loss of tensile strength. The addition of a fourth axis will also be implemented to allow increased complexity of geometrical shaped components along with the removal of the additional required separate step of the separation between the component and the base plate. Each idea, thought, and experiment that produces successful results brings the 3-D Hybrid Printer closer to optimal performance and optimization.

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